Effect of antifungal agents on the activity of aspartyl proteinases secreted by Candida albicans

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The inhibitory effect of human immunodeficiency virus (HIV) proteinase inhibitors amprenavir and saquinavir and antifungal agents terbinafine, ketoconazole, amphotericin B and ciclopiroxolamine on aspartyl proteinases (Saps) secreted by Candida albicans was tested in an in vitro spectrophotometric assay. As expected, both HIV proteinase inhibitors showed a significant inhibitory effect on Sap activity, which was comparable to that of the classical aspartyl proteinase inhibitor pepstatin A (P < 0·001). Antifungal drugs such as ketoconazole, terbinafine and amphotericin B had no, or only minor, inhibitory effects on proteolytic activity. In contrast, a significant reduction in Sap activity could be demonstrated during treatment with the antifungal agent ciclopiroxolamine (P < 0·001). These results point to a multiple effect of this antifungal agent and might explain the reduced adherence of C. albicans to human epithelial cells at subinhibitory doses.

In the last decade, it has been demonstrated that secreted aspartyl proteinases (Saps) are important virulence factors for several types of Candida albicans infections and that inhibition of these proteinases have a protective effect for the host (De Bernardis et al., 2001; Hube & Naglik, 2001). Based on the observation that antifungal drugs may have broad modes of action, we questioned whether certain antifungal components may also influence the activity of Saps, which, in turn, may enhance the antifungal activity of a particular drug. For example, Wu et al. (1999) showed that the natural antimicrobial agent lysozyme not only showed a candidacidal effect at higher concentrations but also decreased the extracellular concentration of Saps significantly without affecting cell growth or viability of C. albicans. In addition, lysozyme also directly caused degradation of purified Sap protein (Wu et al., 1999). Other studies showed that certain inhibitors designed to inhibit human immunodeficiency virus (HIV) proteinase also had a direct effect on the activity of Saps (Korting et al., 1999; Cassone et al., 1999; Borg-von Zepelin et al., 1999). To investigate whether recently designed HIV proteinase inhibitors, such as amprenavir, or antifungal agents, such as members of the allylamines, azoles, polyenes or pyridone antimycotic components, inhibit Sap activity, we measured the effects of selected HIV inhibitors and antifungal drugs on the proteolytic activity of C. albicans using a spectrophotometric assay.

Abbreviations: HIV, human immunodeficiency virus; LSD, least significant difference; Sap, secreted aspartyl proteinase; TCA, trichloroacetic acid.
Stock solutions were prepared for amprenavir, saquinavir and pepstatin A by dissolving in absolute methanol at a concentration of 1·0 M for saquinavir and 100 M for pepstatin A and amprenavir. Amprenavir and saquinavir were diluted with 0·2 M sodium citrate/HCl buffer (pH 4·5) (Merck) to 1·0, 0·2 and 0·1 M; pepstatin A was diluted with sodium citrate/HCl buffer to 0·5, 0·75 and 1·0 M. Terbinafine was diluted in distilled water to 100 M. Ketoconazole and amphotericin B were diluted in dimethyl formamide (Sigma) to 1·0 M. Ciclopiroxolamine was diluted in dimethyl formamide to 100 M. Dilutions were 0·5, 1 and 2 M for terbinafine and ciclopiroxolamine, 0·2, 0·5 and 1 M for amphotericin B and 0·5, 0·75 and 1 M for ketoconazole.

Studies were carried out using bovine haemoglobin (Sigma) as substrate (Korting et al., 1999). Test tubes were each filled with 750 µl 0·2 M sodium citrate/HCl buffer, 750 µl fresh substrate solution (1 % substrate in 0·2 M sodium citrate/HCl buffer), 250 µl each sample and 250 µl amprenavir, saquinavir, pepstatin A, terbinafine, ketoconazole, amphotericin B or ciclopiroxolamine. Control experiments included assays without the addition of antifungal agents or inhibitors. Control experiments also included assays with dimethyl formamide or sodium citrate/HCl buffer alone without addition of antifungal agents or proteinase inhibitors. Test reactions were incubated at 37 °C for 60 min (T60) in a shaker. The reaction was linear with time for up to 60 min. Three triplicate reactions were used for each experiment. Reactions were stopped with 500 µl trichloroacetic acid (TCA) and stored on ice. For each reaction mixture, an additional control was prepared by adding all ingredients (TCA) and stored on ice. For each reaction mixture, an additional control was prepared by adding all ingredients (TCA) and stored on ice. For each reaction mixture, an additional control was prepared by adding all ingredients (TCA) and stored on ice. A 160 µl sample of each cleared supernatant was then added to 40 µl dye reagent (Coomassie brilliant blue G-250, Bio-Rad). Peptides produced by proteolytic activity are not precipitated by TCA and bind to the dye. The amount of peptides in the supernatant can therefore be measured in a spectrophotometer (MR 4000, Dynatech) as a shift in the maximum absorbance value of the dye (measured at a wavelength of 595 nm) and correlated with proteolytic activity. Activity was calculated as the change in absorbance value using the following formula: sample (T60) – control (T0). One unit of activity was defined as an increase in 0·100 per 60 min at 595 nm. Activities were calculated for 1 l of Remold medium at a yeast density of 108 m1. The present study confirms the data published previously for pepstatin A and saquinavir (Korting et al., 1999; Borg-von Zepelin et al., 1999). In addition, a marked and highly significant inhibition of Sap activity by amprenavir could be demonstrated for the first time. These results provide further evidence for a direct effect of HIV protease inhibitors on one of the most relevant virulence attributes of C. albicans. In addition, we also observed that treatment of C. albicans proteinases with the hydroxypryridone antymycotic agent ciclopiroxolamine caused reduced proteolytic activity. Effects were not dose related. A possible explanation for this observation might be an interference of the antifungal agent/proteinase inhibitor at higher concentrations. One possible function of Sap activity is the attachment of C. albicans to epithelial cells and invasion into deeper tissue (Ollert et al., 1993; Watts et al., 1998; Schaller et al., 1999). Braga et al. (1992) investigated the effects of subinhibitory concentrations of ciclopirox on the adherence of C. albicans to human buccal and vaginal epithelial cells. These authors found a significant reduction in adhesion at concentrations from 1/2

![Fig. 1. Effects of pepstatin A ( ), amprenavir ( ), and ciclopiroxolamine ( ) on Sap activity of C. albicans strain 1 (a) and 2 (b)]. Each point represents the mean ± SD for three triplicate determinations. Differences in Sap activity between untreated and inhibitor-treated samples were highly significant (P < 0·001), as determined by the LSD test.

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to 1/16 of MIC$_{50}$ and explained this effect by a reduced intracellular uptake of essential substrates and ions necessary for the ability of _C. albicans_ to express its adherence mechanisms. Our study suggests that ciclopiroxolamine also directly effects the activity of Saps of _C. albicans_, which, in turn, may cause reduced adherence in vivo.

**References**


